PART II. SYSTEM ENGINEER□S GUIDE

CHAPTER 5

IMPLEMENTER/SYSTEM ENGINEER'S HANDBOOK

5.1 Aspects of system design

When the need for a new communications capability between two or more points is first envisioned, and HF radio is suggested as a possible solution, the sponsoring agency must conduct a preliminary system design and feasibility study to analyze and define the requirements. This study will verify that HF is the appropriate means of communication for the set of system requirements pending, and that the costs for the new system are reasonable.

5.1.1 Definition and analysis of requirements

A rigorous analysis of the expectations and requirements for the new system should show whether or not this communication medium is proper for this application. Some of the factors that support the use of HF radio over other means of communication are:

- **Distance**
  The distances between the terminal points are suitable for HF propagation, and are too long for line-of-sight (LOS) radio (with repeaters, if necessary), or for microwave radio. HF radio propagation supports long-distance communications except when conditions are unfavorable.

- **Reliability**
  The reliability of HF radio is not as great as that of other mediums because of its susceptibility to atmospheric disturbances.

- **Terrain**
  Impassible terrain (such as mountains or oceans) or international borders between the terminal points may preclude the use of other media, making HF radio communication a viable alternative.

- **Traffic**
  HF radio communication is typically used for voice or low data rate communication. This alternative is viable if the amount of traffic to be passed via the HF system is small enough to be satisfied by one or two HF radio channels.

- **Priority**

The priority and sensitivity of the traffic is such that the performance and reliability of HF systems will be satisfactory.

- **Costs**
  The costs to install, maintain, and operate the HF system are less than those of any other means of communications that could satisfy the requirements.

- **Solar cycle**
  The predicted long-range propagation forecasts are favorable for the frequency set that is planned to be used.

- **Frequency Set**
  Adequate frequencies to support the HF mission can be obtained. Also if this unit will be operating with other units already using HF radio frequencies, the choice of this frequency band may already be dictated.

- **Real estate**
  Adequate real estate (sites) are or can be made available to support the mission. Typically a HF radio installation would required a larger antenna, making the location (field, building top, *etc*.) of the antenna a major consideration.

A review of the above items will determine if the use of HF radio equipment is appropriate for the proposed application.

5.1.2 Preliminary system design and feasibility study

Once it has been determined that HF is a viable solution to the communications requirement, then a preliminary system design and feasibility study must be conducted. The items which the system engineer must consider make up the remainder of this chapter.

5.1.3 Trunking/routing plans

The trunking and routing plans in the design analysis provide information on the number and types of channels needed to interconnect each of the terminals within the HF system. If the radio system is to be a part of larger network of radios the implementing engineer will work with the network manager to identify all the stations or nodes to be included in the network as well as their geographical locations

The designer of trunking/routing plans must be aware of the physical location of each node and the relationship to other nodes in the network. He/she must identify any physical obstacle (*i.e.*, mountains, buildings, antenna, *etc*.) which may be present in the paths between the various nodes. He/she should be acquainted with the equipment located at each node, especially the power and antenna characteristics. He/she must be keenly aware of all the various propagation paths between the various stations involved (*i.e.*, skywave, groundwave, and line-of-sight). The network manager will need to know details about the characteristics and volume of the communications traffic that will be traveling between the various nodes at various times during the day. He/she must be aware of the communication interfaces that are connected to each node and how the loss of one or more of these interfaces could affect message traffic across the network. The manager must be made aware of the priority of messages through each node as well as the importance of each net member to the total mission of the network. If messages are to be forwarded through intermediate nodes to accommodate the case where coverage may not be universal, this special routing must be considered in his/her traffic analysis.

5.1.4 Frequency plan

Planning must begin early in the project to secure an adequate list of frequencies to support each link in the HF radio system so that uninterrupted operations are possible both day and night, at any time of the year, and throughout the whole 11-year solar cycle. Frequency prediction programs such as IONCAP, ICEPAK, or VOACAP are ideal for determining frequency requirements in different conditions. Annex 2 of this document provides detailed information about these propagation prediction programs and other methods that will aid the implementing engineer in determining a frequency plan.

5.1.5 Personnel manning requirements

To einsure that each station in the network is operated and maintained properly, an analysis of the numbers, training and experience of the personnel that will be required to staff each of the nodes in the network during the required period of service (*i.e.*, 8 hr/day, 12 hr/day, 24 hrs/day, 5 days/wk, or 7 days/wk) should be conducted early in the planning process. Are adequately trained personnel available? Or does the usage of new technology require that all personnel receive training on the new equipment? Who will provide the training? The vendor, an in-house training organization, or a combination of the two? Perhaps, some of the site personnel can receive on-the-job training from other site personnel.

5.1.6 Support requirements

The system designer must select a site having adequate access roads, water and electrical power supply, fuel for generators, telephone service, post office, medical facilities, and adequate housing and shopping areas for site personnel. In the vast majority of cases, the radio site will be located near a city or large town, and the support considerations mentioned above, will normally be available. But in a few cases obtaining these services may require special logistics effort.

5.1.7 Local user requirements

Local users' requirements include characteristics that may be specific only to this site. Some of these characteristics may include:

1. Priority or special messages needed only on this site;

2. Special licenses or building covenant releases, environmental impact statements (see Section 5.1.16);

3. Special power or communication needs specific to this site.

5.1.8 Modes of communications required (voice, data, image)

The original requirements from the using agency will specify what type(s) of traffic the HF station must be capable of handling. This may be voice only, both voice and data, or may indicate the need to handle other forms of information, such as image, facsimile, or encrypted voice. Each of these types of traffic will indicate additional pieces of equipment that must be considered by the system engineer.

5.1.9 Required Signal-to-noise ratios

The modes of communications required (*i.e*., voice, data, *etc*.) Will determine the required SNR. CCIR Recommendation 339-5 or similar guidance can be used to determine what SNR is needed for the required grade of service (orderwire quality, marginal commercial grade, or good commercial grade).

5.1.10 Modulation data rates

Information is transmitted in communications by means of sending time-varying waveforms generated by the source and transmitted to the destination. These waveforms may use either analog or digital techniques for coding. In radio communication, the varying waveforms derived from the source are transmitted by changing parameters of a sinusoidal wave at the desired transmission frequency. This process is referred to as modulation, and the sinusoidal is referred to as the carrier [Ulrich *et al*., 1988]. The radio transmitter must modulate the carrier before it is emitted from the antenna. The radio receiver must be designed to extract (demodulate) the information from the received signal. For analog systems the carrier wave is modified by the transmitter based on a information waveform. The analog receiver must demodulate the carrier to return to the information waveform. For digital systems the transmitter imposes a code based on the desired carrier information that must be decoded by the receiver and turned back into the original information. Important characteristics of a particular system are expressed in terms of distortion, error rate, bandwidth, occupancy, cost, *etc*. [Ulrich *et al*., 1988]

To review the differences between analog and digital we offer the following explanations:

a. Types of signals

(1) *Analog signals*

An analog signal is a continuous signal that varies in some direct correlation to a signal impressed on a transducer such as a microphone. The electrical signal may vary its frequency, phase, or amplitude, for instance, in response to a change in phenomena or characteristics such as sound, light, heat, position, or pressure. Analog signals do not lend themselves to extraction of signal from noise (regeneration) because there is no way to distinguish between the signal and any noise and distortion.

(2) *Digital signals*

A digital signal is a discontinuous electrical signal that changes from one state to another in discrete steps. The electrical signal could change its amplitude or polarity, for instance, in response to outputs from such devices as computers and teletypewriters. An analog signal such as voice may be converted to a digital form with an analog-to-digital converter and back to analog by a digital-to-analog converter.

(3) *Quasi-analog signals*

A quasi-analog signal is a digital signal that has been converted to a form suitable for transmission over an analog circuit. An important consideration in the use of quasi-analog signal transmission is that, while the signal remains in quasi-analog form, no signal regeneration can be performed.

b. Types of modulation

The modulation types discussed in this manual are defined in Table 5.1.

TABLE 5.1
Types of modulation

Designator	Modulation Form	Definition
cw	continuous wave	Defined as a radio wave of constant amplitude and constant frequency. As a modulation form, cw is defined as an interrupted continuous wave which is on-off keyed using Morse code.
AM	amplitude modulation	A form of modulation in which the amplitude of a carrier wave is varied in accordance with some characteristic of the modulating signal.
FM	frequency modulation	Amplitude changes of the modulating signal are used to vary the instantaneous frequency of the carrier wave from its unmodulated value.
SSB	single sideband	A form of amplitude modulation in which the carrier and one sideband are suppressed and the remaining sideband is transmitted. Also designated as USB and LSB, for upper and lower sideband.
ISB	independent sideband	A method of double-sideband transmission in which the information carried by each sideband is different.
RTTY	radio teletypewriter	A teletypewriter used in a communication system using radio circuits. Mark/space teletypewriter signals are modulated on radio systems either by a two-frequency shift of the carrier wave, called frequency-shift keying (FSK) or by a two-frequency audio signal, called voice frequency telegraph (VFTG) or audio frequency-shift keying (AFSK).
Data	binary digital	Information that is represented by a code consisting of a sequence of discrete elements. Digital data is produced by teletypewriters, digital facsimile equipment and computer terminals, among other sources. The signals are generally transmitted by digital-to-analog conversion to frequency-shift keying or phase-shift keying (PSK).

c. Modulation data rates

Normally this information will be furnished the system designer with the equipment specifications. Most modern HF data modems will be capable of several data rates. Care must be taken to assure that equipment interfaced together operates at the same data rates and uses the same modulation types.

5.1.11 Types of service (full time, on-call, encrypted, *etc*.)

This information will generally be provided with the initial system requirements.

5.1.12 Required circuit reliability

HF circuits are able to provide circuit reliability of 80% (19.2 hours/day) to 95% (22.8 hours/day). Modern, adaptive equipment such as ALE will operate near the high end of the reliability spectrum.

5.1.13 Terminal facilities required

The terms *terminal facilities* are used here to describe all of the physical plant, primary and auxiliary power, and environmental control systems required to support the new HF system.

5.1.14 Required system lifetime of service

The length of time that the new HF system will be expected to be in service, will have an impact on the selection of equipment. If the service is only for a short period of time (several months to a few years), it may be possible to operate with transportable or tactical equipment. Any longer life expectancy will usually require permanently installed equipment.

5.1.15 Real estate requirements

Because of the long wavelengths involved with HF operations, large amounts of real estate are required for HF stations. A simple dipole antenna usually requires at least one acre of ground, and a rhombic antenna can require from 5 to 15 acres. If the new HF system cannot use an existing site, then planning must begin very early in the project to find and acquire a suitable location. Additionally, if operation is contemplated on several circuits or full-duplex operation on one circuit, then the various antennas must be separated to prevent co-site interference. This antenna separation compounds the need for additional real estate. Sections 5.2.4 and 5.2.7 give more details on antenna site selection.

5.1.16 Environmental Impact Assessments

Frequently, the construction of an HF radio site, or the upgrade to an existing site, will require environmental impact assessments. This requirement is, more and more, becoming the norm, rather than the exception. If towers in excess of 200 feet are anticipated, or if the site is or planned to be located near an existing airport or heliport, then notification of the Federal Aviation Administration (FAA) is required.

5.1.17 Required operational date

The date that the station is required to be operational (or the new equipment is required to be operational) may be given in the original statement of requirements, or it may require negotiation with the operational agency. Some of the major system components may have delayed delivery times, so their delivery schedule should be factored into the plans for an operational date.

5.1.18 Cost estimate

The total project cost of development of a new or expanded HF radio capability includes more than just the cost of the equipment. This section contains the direct and indirect project costs including details about:

1. Start-up costs,
2. Equipment costs,
3. Installation costs.

5.1.18.1 Startup Costs.

- **Project management costs**
  Cost estimates must include the cost of direct and indirect labor for the project manager and any staff, for the time spent monitoring and managing the project. Also included are other direct costs, such as travel costs.

- **System engineering costs**
  Cost estimates must include the direct and indirect labor costs of the system engineer and any assigned staff, for time spent reviewing the project requirements, and the time devoted to system design work. These costs may also include other direct costs for items such as travel, printing, drafting, *etc*.

- **Real Estate/land acquisition costs**
  If the site for the new HF station(s) is/are not owned by the operational agency, the site(s) must be acquired through purchase or lease. These acquisition costs include all costs associated with the acquiring of the land for the site(s), including the purchase, yearly lease, legal fees, and any taxes that apply.

- **Site preparation costs**
  These costs include costs associated with leveling or grading the land, constructing fences, digging trenches for antenna cables, constructing concrete piers for antenna towers, as well as the major costs listed below.

- **Construction or modifications to equipment building(s)**
  If the site is a new one, then an equipment building/control facility must be constructed to house the equipment and to provide a place for the site's personnel to operate. If the site is

an existing one, then it may be necessary to construct additional rooms for the site building(s) to house the new capability.

- **Construction or modifications to the site's primary and auxiliary power system**
  The HF system requires ac power, from the local power company grid to run the HF equipment and site to provide support for equipment such as heating, ventilation, and air-conditioning (HVAC). If the site is an existing one, this power may be already provided, but in many cases the power distribution system may have to be upgraded with larger transformers, and additional circuit breakers. The engineering plan may also call for the installation of an auxiliary power source, such as a gasoline- or diesel-powered electrical power generator for emergency use.

5.1.18.2 Equipment costs

- **Equipment purchases**
  The cost of the HF system equipment may or may not be the largest cost of the project, depending on how many circuits are required, what power levels the transmitters require and the distances between sites. Equipment is usually purchased through one supplier or vendor, although it is not uncommon for multiple vendors to support a large contract. The usual process is for the using agency to notify all qualified vendors of intent to purchase equipment and/or services, through the Request for Proposal (RFP). The interested vendors respond to the RFP with their proposed solution to the customer's need, and with a cost estimate. The customer can then choose among several competing solutions, and choose the one that best meets their needs. The vendors, often will propose a "turnkey solution", whereby they will provide not only all the required equipment, but will also provide or subcontract the installation and site-preparation work as well. The following is a listing of the most common components of an HF radio system,
    1. Transmitter/receiver or transceiver,
    2. Antenna components,
    3. Antenna switches,
    4. Transmission lines,
    5. Terminating devices,
    6. Multicouplers,
    7. rf patching,
    8. Terminal equipment,
    9. Voice terminals,
    10. Audio patching equipment,
    11. dc patching facility,
    12. Spare parts facility.

Annex 3 of this document is a tutorial explanation of the basic elements of an HF radio system.

- **Transmitter/receiver or transceivers**

Depending on the power levels required, the station might be equipped with either transceivers or separate transmitters and receivers. For low-power to medium-power operations, say from 100 W to 1000 W, it is the usual practice to use transceivers (a combination of transmitter and receiver in the same package). For high-power operation, >10 kW, the standard practice is to run a split site, with the transmitters at one location and the receivers at another. This configuration allows for full-duplex operation, if required.

- **Antenna components**
  Antennas used in the HF radio operations range from a simple, thin wire, half-wave dipole to large, fixed, or rotatable log-periodic antennas or rhombic antennas, covering many acres of land. The selection of antennas depends on the number of frequencies to be covered, the rf power levels used, and the circuit-reliability requirements. Whether or not the antenna has an omnidirectional or directional pattern is a function of where the stations to be contacted are located. Additional antenna subsystem components that may be needed are transmission line (balanced or coaxial), antenna switching matrix, multicouplers, terminating devices, impedance matching networks, and high- and low-level rf patching. Sectopms 5.2.4 and 5.2.7 give more details on antenna selection.

- **Antenna switches**
  Antenna switches are found where there are multiple antennas or where different antennas are to be used for different circuit paths. The switch allows the radio operator to switch antennas by a manual switch, located in the radio room, or electrically, from a control console.

- **Transmission lines**
  Transmission line is used to connect the transmitters/receivers to the antenna. They are selected during the detailed engineering phase, based on the transmitter power, system impedance, possibility of coupling with other nearby lines, line loss, cost, and atmospheric environment. In general, low- to medium-power transmitters (100 W to 1000 W) use some form of coaxial cable for transmission line, while high-power stations (>10 kW) use open wire, balanced transmission lines.

- **Terminating devices**
  Terminating devices are used with nonresonant antennas, such as long wires, Vees, and rhombics to make them unidirectional. There are two types of terminating devices: a lumped constant (nonreactive resistance) and a distributed constant (lossy transmission line) terminating device. These terminating devices are provided in the characteristic impedance of the particular antenna, and must be capable of dissipating (at least) the average power of the transmitter.

- **Multicouplers**

Multicouplers are devices used to permit two or more receivers or transmitters to share the same antenna. In general, only low-powered transmitters use multicouplers, due to the amount of isolation required between transmitters.

- **RF patching**
  Low-level rf patching is used to interconnect equipment when frequency synthesizers or exciters are used with linear power amplifiers. The output of the synthesizers or exciters is usually on the order of a few milliwatts. High-level rf patching is used to interconnect low-powered transmitters (100 W to 500 W) to linear power amplifiers.

- **Terminal equipment**
  For the purpose of this handbook, terminal equipment will include all other ancillary equipment, such as voice terminals, audio switchboards and patching, dc patching and teletype terminals, multiplexors for voice-frequency carrier telegraph (FVCT), facsimile equipment, HF data modems, and crypto devices.

- **Voice terminals**
  Voice terminals provide the interface between the customer's equipment and the transmission system, call signaling, electrical isolation between the transmit and receive paths, and signal conditioning.

- **Audio patching equipment**
  Every HF terminal station should have some form of audio patching. It can be as simple as a single jack strip or many jack strips. The purpose of this patching facility is to give the station personnel the ability to have access to all of the audio circuits for:

  1. emergency traffic routing
  2. switching or substituting equipment
  3. monitoring the signal quality
  4. circuit test and maintenance.

  All incoming, outgoing, and most of the intra-station audio circuits will appear on the audio patch. For small installations, the audio patch may be located with the other equipment. In larger sites the audio patch will be separately located and manned, and may even be in a separate building. The audio patch plugs and jacks ***must*** be a different size from the dc patching equipment, to prevent patching errors.

- **dc patching facility**
  A dc patching facility is required if teletypewriters or other dc equipment is present. This patch may be a single- or multiple-jack strip, and is usually co-located with the other ancillary equipment.

- **Spare parts**
  The mission of the site may dictate at what level spares are kept. If the station has a 24-hour per day mission it may need to keep not only spares such as fuses, coaxial jumper cables, *etc*., but may also need to have spare equipment available to swap out with defective equipment, to keep the station operational. Agency policy or regulations may also dictate the storage of additional spare parts.

5.1.18.3 Installation costs

Other items to be included in the cost estimate deal with the installation process. These costs might include the following:

1. Bill of materials for installation,
2. Costs of outside consultants/professional engineers,
3. Costs of installation labor,
4. Cost of acceptance testing,
5. Training of site personnel,
6. Lifecycle Costs.

- **Bill of materials for installation**
  The installation Bill of Materials (IBOM) is a list of every piece of equipment and parts needed to construct (or upgrade) the HF station(s). In addition to the major items, such as antennas, transceivers, *etc.,* the IBOM includes such things as wire, cable circuit breakers, cable trays, screws, nails, *etc*. The IBOM is finalized only after the detailed engineering has been completed. Rules of thumb, or previous projects may provide estimated cost data for the initial stages of system planning.

- **Cost of outside consultants/professional engineers**
  Consultants or professional engineers are frequently employed for specialized tasks, such as locating suitable sites or measuring the local electrical noise levels (both man-made and natural).

- **Cost of installation labor**
  Unless this service is to be furnished by the equipment vendor (through a subcontract), it must be planned for by the project manager. Installation cost includes the cost of all construction required to make the site operational (*i.e.,* construction which was not completed during the site-preparation phase).

- **Cost of acceptance testing**
  Testing equipment is an important part of making the site fully operational. The test plan may call for formal testing of each feature of the new equipment, either by the receiving agency or by the vendor under user agency observation. Or testing may be as simple as providing a period of time, such as 30 days, where the site personnel are expected to check

out all of the equipment features. Direct and indirect labor costs of this testing must be included in overall project costs. Development of suitable test plans may be required if none exist. If these test plans are required, the effort associated with their development is another project cost that must be considered.

- **Training of site personnel**
  Training of site personnel on any new equipment installed during the project, must always be considered. Training may be provided under the equipment purchase contract, or if the agency is large enough to have in-house trainers, they may receive training from the vendor, then provide in-house training for the site personnel. In a small number of cases, the site may have a few personnel already trained, who can provide an on-the-job training program for the site's remaining personnel. No matter how it is accomplished, training must always be included in the project plans.

- **Lifecycle costs**
  Lastly, the system designer must consider the lifecycle costs of the system. These costs include the recurring costs to operate and maintain the new capability.

5.2 System analysis and design

The steps to system engineering a typical HF radio system might include the following three levels of planning.

1. The first is an analysis of the requirements for the communications system, to establish that the use of HF radio is feasible,

2. The second level of planning is to develop cost data to substantiate project funding requests and approvals,

3. Lastly, the third level of planning is the detailed engineering analysis. This detailed engineering is the subject of this section.

5.2.1 Network topology

For the cases where the HF ALE radio unit may be involved in a network configuration, one of the first steps in the system analysis and design is to the consider the network system needs. A network in communications may be defined as a method of connecting nodes so that any one radio unit in the network can communicate with any other radio unit. In the case of the Radio Frequency (rf) world where no physical connections are involved this amounts to having the units have a bonding that somehow makes these units common to some topology. To see how this bond might happen let us first look at how the units might have a virtual connection. Three of the more common methods of connection that exist in conventional telecommunications that would be applicable to our application: (1) the mesh, (2) star, and (3) double and higher order star. Figure 5.1 shows examples of each of these connections.

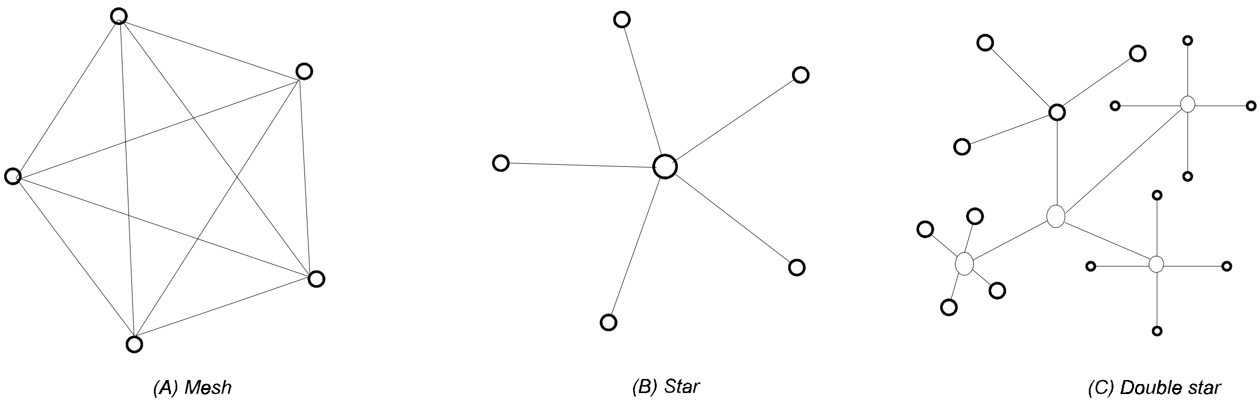


FIGURE 5.1
Examples of network topology

The mesh connection is one in which each and every exchange is connected by paths to every other exchange. Other network configurations are illustrated in Annex 8, under "*network topologies*." The mesh connection would be the typical connection between units assuming a) nothing unusual is done, b) propagation exist between all units, c) all units are on the same frequency, and d) addressing considerations allow for communication. A star connection utilizes an intervening exchange, called a *tandem exchange*, such that each and every exchange is interconnected via a *single* tandem exchange. A star configuration would be useful in a situation where a central node is in control and all messages pass through this node before being dispersed to each node individually. An example of this type of topology might be a central command sending all messages to subordinate units. Possibly the most useful topology might be a double star configuration where sets of pure star subnetworks are connected via high-order tandem exchanges, as shown in Figure 5.1. This trend can be carried still further such as when hierarchical networks are implemented. In HF ALE radios the mesh topology would be used normally, while the star and double star would be implemented using special addressing techniques where a common call would receive responses from all members of the network. Each receiving member would respond to the sender in a time division multiplex access (TDMA) time slot defined for that unit.

As the system design progresses, a network topology plan should be developed. Usually this task is done with the help and agreement of the network manager. Since it will typically be the network manager's responsibility to maintain the network after its development, it is important to involve both the system integrator and network manager in the design phase. Using the objectives and requirements as a basis, the analysts can perform a *network design*. The design should give details about the network topology, network layout, and site selection. The network topology may be chosen based on where the traffic originates, the destination to which it is to be transmitted, and the projected data flow. The topology chosen could be point-to-point, star, mesh, multiplexed, *etc*. The topology might consist of a single network or a multi-network environment (*i.e*., a collection of networks linked together for communication). A traffic analysis can be used to show where traffic may be high or low, sporadic, priority, or non-priority.

In some cases the radio unit will contain the logical functions of a network controller. The network controller contains many higher level functions to add a degree of network automation and adaptivity to the radio unit. These functions can include message routing, message acknowledgement between adjacent nodes, and flow-control mechanisms to protect node resources from being exhausted. The network controller operates to interface the local communications channel with network users and to manage this channel to provide error-free transmissions. The requirements of a network controller may range from handling link errors to managing topology. The requirements may be grouped into three categories: source/destination, store-and-forward, and network-wide functions [1].

Source/destination functions provide the protocols required to permit communication between network users. These are the protocols that are required to interface with network users' equipment.

Store-and-forward functions are the functions that provide the services for message transmission ***through*** a network controller.

Network-wide functions pertain to the management and maintenance of the network, and the measurement of its behavior. These functions include preventing network-wide congestion, maintaining topological awareness, bringing up or taking down network nodes or links, and measuring network performance [14]. These functions may be centralized in a single node of the network such as with a Network Control Station (NCS). In this case, a control node performs all of these functions with minimal involvement from the other nodes. Alternately, each node may individually perform most of the functions and periodically update the control node.

5.2.2 Approximate geographical coordinates for each station

Once an approximate location for the station has been selected (or an existing site is selected for use), the latitude and longitude for the station can be determined. If an existing site is to be used, the geographic coordinates will be known (and can be checked by the use of a hand-held GPS receiver). If the site has not yet been firmly determined, an estimate of its geographic coordinates can be made from a recent topographic map.

5.2.3 Tentative site selection

The selection of an HF radio site requires a detailed analysis of the physical surroundings in which the radio site must function. Above all, the site chosen must be technically adequate. Specifically, the engineer must consider the site's noise environment, ground conductivity, the obstacles in the foreground, and things such as buildings or mountains nearby that would obstruct the received or transmitted signals. Secondary considerations include ease of construction, access to utilities (water, electrical power, *etc.*) and access to the site. But, the technical adequacy of the site is the most important factor.

5.2.4 Path operational parameters

The purpose of making the propagation forecast is to estimate the optimum frequency to be used and to predict the system performance throughout the 11-year solar cycle and throughout the whole year. These propagation forecasts are used by the design engineer to select the proper equipment for the path.

Annex 2 of this document provides detailed information about propagation prediction methods that will aid the implementing engineer.

5.2.4 Propagation forecast

An integral part of system design and analysis for an HF radio communication system is determining the atmospheric conditions through the use of a propagation forecast. The following details must be considered before an accurate propagation analysis may be made.

1. Site noise environment,
2. Antenna characteristics,
3. rf power available,
4. System gain.

- **Site noise environment**

  Atmospheric and man-made noise at the site should be measured throughout the day. Ideally, a site should be selected that is far from areas of high-noise concentration (*i.e.*, far from industrial and residential areas and airports). If possible, atmospheric noise should be greater than any man-made noise at the receiver site. If it is not possible to measure atmospheric noise throughout the entire year, estimates can be made by reference to CCIR Report 322-3, *Characteristics and Applications of Atmospheric Radio Noise Data*, International Telecommunication Union, Geneva, 1988. This ITU report provides information on local atmospheric noise for different times of the day and for each of the four seasons of the year.

- **Antenna characteristics**

  The primary selection factors which determine the antenna best suited for a particular application are:

  frequency range

gain,
directivity, take-off angle, vertical and horizontal radiation pattern,
total radiated power,
size and complexity, land area requirements,
beamwidth,
antenna bandwidth,
input impedance.

Since we are dealing with HF antennas, our interest is in the 2-to-30-MHz range. Gain is the ratio of the power density radiated by the antenna in a given direction to that radiated by a reference antenna (usually an isotropic source) when both have equal input powers. Directivity is the ratio of the maximum power radiated by an antenna to the average radiated power. Gain and directivity are related in that increased gain is accompanied by greater directivity. This is because the total radiated power remains constant. Thus, an increase in power in some directions results in a decrease in power in other directions. Generally, directivity is considered in terms of vertical (take-off angle) and horizontal (azimuthal beamwidth) angular patterns. The many types of antennas in common use in HF radio provide different combinations of the essential characteristics to meet specific radio link needs.

Table 5.2, HF Antenna Characteristics, shows many of the important characteristics of HF antennas. Table 5.3 is another comparison of antenna characteristics base on the concepts of unidirectional (single direction) and omnidirectional (receiving or sending equally in all directions) patterns. Figure 5.2 shows how an antenna can have a directional pattern and shows how the take-off angle affects the transmission of maximum power over an obstacle. This diagram is for the vertical plane, but, it would look very similar if it were plotted looking down (horizontal plane). The horizontal directivity is important because the antenna can be physically located or directionally turned toward the direction of interest. This increase in power in the direction of interest shows pictorially the concept of gain described in the previous paragraph.

TABLE 5.2

HF Antenna Characteristics

Antenna Type	(Note 1) Freq Range (MHZ)	(Note 2) Bandwidth	TakeOff Angle/Deg	Horizontal Angle/Deg	Gain (dBi)	Land Area Required Acres	(Note 3) Range	(Note 4) Use
Dipole	2-30	Narrow	10-90	80-2	2	1	S-M	G-N
Inverted V	2-30	Narrow	40-90	OMNI	2	1	S	G-N
Inverted L	2-30	Narrow	20-90	80-180	3	1	S-M	G-N
Vehicular Whip	2--30	Narrow	20-50	OMNI	-3	Vehicular	M	M
Vertical Quarter-wave	2-30	Narrow	5-40	OMNI	3-5	1	M-L	G-N
Quad Loop	5-30	Narrow	10-90	80-120	3	1	M	G-N
Long Wire	3-30	Broad	10-30	10-30	4-10	3	M-L	P
V Antenna	3-30	Broad	5-30	5-30	4-16	4	M-L	P

Yagi	7-30	Narrow	10-35	30-60	7-12	1	M-L	G-N
Half Rhombic	3-30	Broad	10-40	5-30	5-12	3	M-L	P
Vertical LPA	4-30	Broad	5-40	100	6-12	3-5	M-L	P
Horizontal LPA	2-30	Broad	10-45	40-75	8-16	2-6	M-L	P
Rotatable LPA	4-30	Broad	5-50	60-70	8-12	1	M-L	G-N-P

NOTES:

1. Frequency range is typical of the antenna type (not of an individual antenna).
2. Radiation angles are for comparison purposes. Values represent average range. Actual values depend on ground conductivity, antenna height, and operating frequency.
3. S-Short-0-400 km (0-250 mi); M-Medium-400-4000 km (250-2500 mi); L-Long-over 4000 km (2500 mi).
4. G-Ground-to-air; M-Mobile; N-Net station, fixed; P-Point-to-point L-Long over 4000 km (2500 mi).

TABLE 5.3
Additional HF Antenna Characteristics

Antenna Types Listed by Azimuthal Patterns and Polarization	Useful Frequency Range (MHZ) (Note 1)	Power Gain (Referred to Istropic) (dB) (Note 2)	Usable Radiation Angles (degrees) (Note 3)	Land Required (acres)	Approximate Material Cost ($ thousands) (Note 4)
Unidirectional Patterns					
Horizontal Rhombic	2-30	8 to 23	4-35	5-15	5-10
Terminated V	2-30	6 to 13	5-30	4-9	3-6
Horizontal Log-Periodic	2-30	10 to 17	5-45	2-10	15-25
Vertical Log-Periodic (Dipole)	2-30	6 to 10	3-25	3-5	20-30
Yagi (Horizontal	6-30	12 to 19	5-30	<1	5-10
Billboard (Horizontal)	4-30	9 to 17	5-30	1-2	10-15
Vertical Log-Periodic (Monopole)	2-30	4 to 8	3-25	3-5	20-30
Horizontal λ 2 Dipole	2-30	5 to 7	5-80	<1	1-2
Omnidirectional Patterns (Vertical)					
Conical Monopole	2-30	-2 to +2	3-45	2-4	5-15
Discone	6-30	2 to 5	4-40	<1	10-20
Inverted Discone	2-16	1 to 5	5-45	2-4	15-25
Sleeve (Not within the limits specified for antenna design in para. 3.2.2.2.6.1.4, it is included due to its widespread use)	2-25	-1 to +3	4-40	2-4	3-8
Vertical Tower	2-30	-5 to +2	3-35	2-4	5-10

Note 1 - The useful frequency range is the range of the antenna type, not necessarily the bandwidth of an individual antenna.

Note 2- Typical power gains are gains of antennas over good earth for vertical polarization and poor earth for horizontal polarization.

Note 3- Usable radiation angles are typical radiation angles over good earth for vertical polarization and poor earth for horizontal polarization; lower angles may be possible for vertical antennas over better earth, *e.g.*, sea water.

Note 4- Approximate material costs include steel towers, guys, and installation hardware. Costs are established only to provide a relative basis of comparison of one antenna against another.

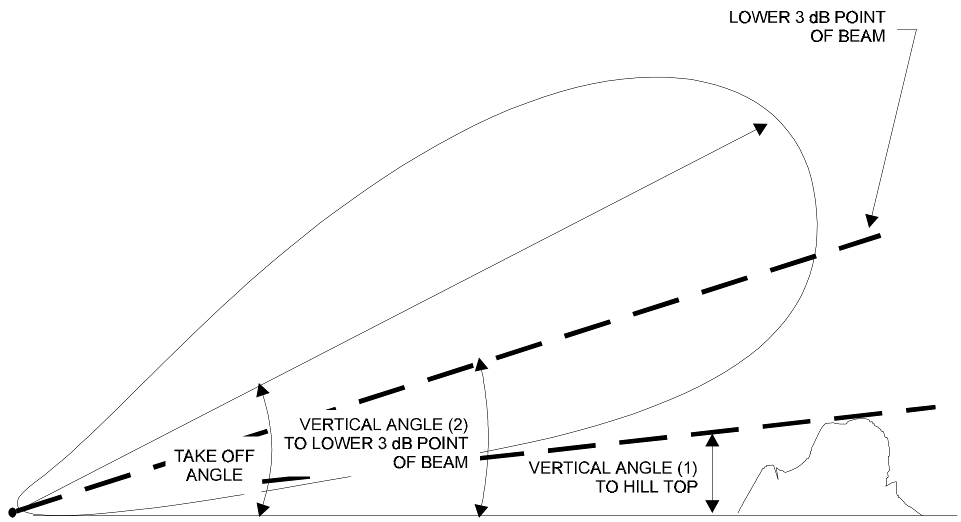


Figure 3-1. Minimum obstruction clearance angle

FIGURE 5.2
Minimum obstruction clearance angle

Frequency range of operation

The frequency range of operation determines the bandwidth requirement of the antenna. The frequency range of operation is determined based on a computer-operated propagation analysis program to determine the optimum traffic frequencies (FOT) for the path involved. An assigned frequency near or below the FOT is then used. Computer-based propagation programs are discussed in Annex 2. As a rule of thumb, the frequency ranges in Table 5.4 propagate the distances shown under normal ionospheric conditions.

Bandwidth

The bandwidth is the band over which the communication system can be used without modification to the antenna or its tuning. Antennas can be categorized as narrowband (*e.g.*, dipole or Yagi) or broadband (log-periodic or vertical half rhombic).

The vertical angle

The vertical angle of maximum radiation of the antenna is the takeoff angle (TOA). This angle marks the center line of the lobe of radiation above and below this median angle. The required TOA depends on the distance between stations, the height of the ionospheric layer, and the mode of propagation (number of hops and layer used). Table 5-5 shows the required TOA in degrees above the horizon for single hop daytime and nighttime operation. The values given are approximate and will vary greatly under differing conditions. However, the accuracy is sufficient for broad beamwidth tactical antennas. The mode of skywave operation (number of hops) should be estimated. Table 5-6 shows the number of F-layer hops which normally occur over different distance ranges. Multihop propagation mode TOAs can be approximated by dividing the total circuit distance by the number of hops and using the results as a link distance in Table 5.5. A more accurate procedure to determine TOA is contained in appendix C of FM 11-487-4/TO 31-10-24.

The horizontal range

The horizontal range of radiation angles (beamwidth) required for an antenna is determined by the area to be covered. Multipoint or net operation may require a broad or omnidirectional radiation pattern while point-to-point circuits can use narrowbeam, higher gain, directional antennas.

The gain

The gain of an antenna at the desired takeoff angle and azimuth can be determined by the vertical and horizontal radiation patterns which are depicted in earlier paragraphs in this chapter. Generally, antenna selection is based on the highest gain available in the desired direction.

TABLE 5.4

Propagation frequencies

Frequency range (MHZ)	Path length	
	km	(mi)
2-7	0- 320	(0- 200)
3-8	320- 640	(200- 400)
4-11	640-1290	(400- 800)
5-18	1290-2580	(800-1600)
7-28	2580-9650	(1600-6000)

TABLE 5.5
Take-off angle vs. distance

Take-off Angle (Degrees)	Link Distance: F_2 Region Day Time km	mi	F_2 Region Night Time km	mi
0	3220	2000	4500	2800
5	2410	1500	3703	2300
10	1930	1200	2900	1800
15	1450	900	2550	1400
20	1125	700	1770	1100
25	965	600	1610	1000
30	725	450	1330	825
35	644	400	1125	700
40	565	350	965	600
45	443	275	805	500
50	403	250	685	425
60	258	160	443	275
70	153	95	290	180
80	80	50	145	90

TABLE 5.6
Number of hops for distances

Hops	Distance (km)	(mi)
1	less than 4000	(less than 2500)
2	4000- 8000	(2500-5000)
3	8000-12000	(5000-7500)

Physical size

A significant factor in HF antenna selection is the physical size of the site required for erection of the antenna. An antenna site should be a clear flat area with no trees, building, fences, power lines, or natural terrain obstructions. Large HF arrays require large land areas. Lack of available space may dictate the selection of smaller antennas with less gain.

Antenna selection procedures can be conducted in the following steps:

(1) Determine the frequency range of operation and select the bandwidth required. If a broadband antenna is required but not otherwise available, two or more narrowband antennas constructed to the available frequency complement may be selected.

(2) Determine the required takeoff angle for the required path distance using Table 5.5.

(3) Determine the area of coverage required: omnidirectional, bidirectional, or point-to-point coverage.

(4) Determine from tables 5.2 and 5.3, or by references to previous paragraphs, the antenna which possesses the desired properties and produces the highest gain in the desired direction. Check to determine if the chosen antenna can be erected in the available space. If the antenna is to be constructed on site, check to see if the required materials are available. If space and materials are not available, a lower performance antenna may have to be selected.

5.2.5 Equipment selection

The following is a listing of the most common components of an HF radio system,

1. Transmitter/receiver or transceiver,
2. Antenna subsystem
3. Voice frequency interfaces
4. Digital Interfaces
5. Transmission lines.

Annex 3 shows the elements of an HF radio system.

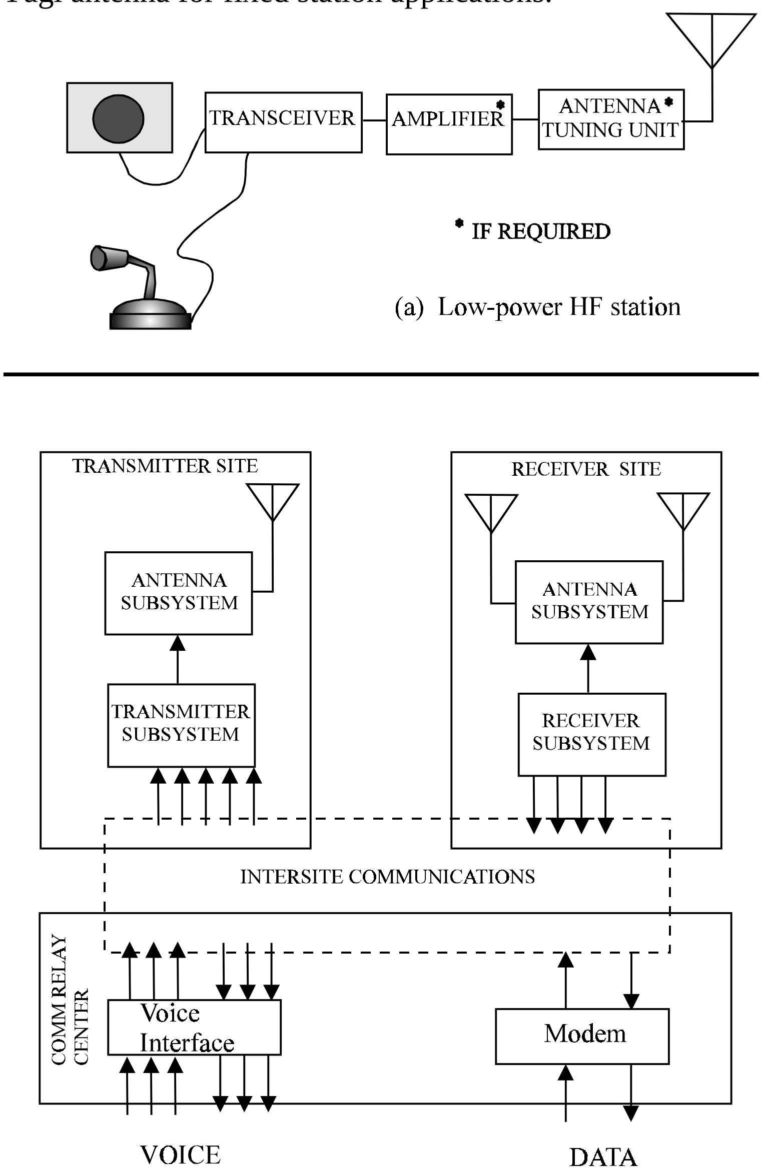
- **Typical HF systems configurations**

a. Single channel systems

(1) *Continuous wave (cw).* In the early days of radio, a telegraph key was used to switch the radio frequency (rf) carrier on and off in accordance with a telegraph code. Since the rf was a continuous wave when it was on, this form of transmission was called interrupted continuous wave. It is most often referred to simply as continuous wave (cw). Most commercial and military equipment have a backup cw communications capability. The cw form of communication is useful as emergency communications when other forms of transmission cannot be used. The cw form is also used in a form of transmission known as burst communication in which telegraph code is recorded in advance and transmitted in short, high-speed bursts. The purpose is to evade enemy interception of the transmission and location of the transmitter.

(2) *Single sideband (SSB) voice.* SSB voice stations are typically small size, frequently desk top transceivers. Power output is usually about 100 watts (W). Coupled with a linear amplifier, output will normally range from 400 to 1000 W. Figure 5.3 illustrates a typical low-powered single channel HF station. There are many military uses for SSB voice systems such as command and control nets, administrative networks, Military Affiliate Radio Service (MARS), ground-to-air and

air-to-ground communications, convoy control nets, other mobile applications, and engineering circuits for transportable communications systems. Typical antennas may be a whip for mobile and transportable applications, a simple dipole, or a rotatable directional array such as a log-periodic or Yagi antenna for fixed station applications.



(a) Low-power HF station

(b) Multichannel HF radio system

FIGURE 5.3

Low power HF station and Multichannel HF radio system

b. Multi-sited systems

(1) *Medium power independent sideband station*

Unlike small, low-power installations where transmitters and receivers can be co-sited, larger, higher power (over 1000 W) multichannel HF facilities (see Figure 5.3(b)) usually require separate transmitter and receiver sites with a normal separation of 8 kilometers (km) (5 miles (mi)) or more. A third facility, the communications relay center (CRC) may be necessary. The CRC performs the control, switching, and message processing activities. The sites are interconnected by a multichannel telephone link, either by multipair cable or by microwave radio.

- **Transmitter subsytem**

Transmitting equipment may be procured in a number of configurations with separate components or as completely self-contained end items. Large transmitters are usually configured into functional components including a frequency synthesizer, exciter, and a power amplifier section. Transmitter exciters are available which provide from one to four independent 3-kilohertz (kHz) channel inputs. The four voice channels are used to provide the four-channel input to the independent sideband mode. More details about the transmitter subsystem are included in Annex 3 of this handbook.

- **Receiver subsystems**

Most current receivers designed for larger HF facilities are tunable by the use of a frequency synthesizer. A synthesizer may be a separate component or it may be an integral component of the receiver. More sophisticated frequency control techniques now available use microprocessor-controlled tuning mechanisms for rapid and accurate frequency changes. Independent sideband (ISB) receivers are designed to provide the four 3-kHz voice frequency channels to the voice frequency termination and multiplex equipment. More details about the receiver subsystem are included in Annex 3 of this handbook.

- **Transceiver systems**

A transceiver is a transmitter, receiver and interface combination.

- **Antenna subsystem**

A typical large site antenna subsystem consists of all items related to the antennas, including the transmission lines, the antenna curtains, supports, dissipation lines (if applicable), switching and impedance matching devices, and entrance devices to the equipment shelters or site buildings. Descriptions of various antenna subsystems and considerations to be made in the choice of antenna are contained in Section 5.2.4 and Annex 3.

- **Voice frequency interface equipment**

Voice frequency interface equipment provides the interconnection between the subscriber and the transmission system. Interface equipment provides the in-band signaling, equalization, attenuation, amplification, or other signal conditioning that is needed for an interface between the transmission means and the voice frequency end instrument.

- **Transmission lines**:

Transmission lines are basically of two types: balanced lines and unbalanced lines. Balanced transmission lines have two identical conductors or groups of conductors operated at equal potential (but opposite polarity) from ground. Unbalanced lines have one conductor above ground potential and the other at ground. Both types of lines may be enclosed in an external shielding conductor.

a. Coaxial line. A coaxial line is an unbalanced, shielded transmission line designed with one conductor in the center and the other as a hollow cylinder completely enclosing the center conductor. When properly designed, the outer conductor gives near perfect shielding since it is normally grounded, resulting in very little pickup of outside interference. This characteristic, more than any other, makes the coaxial transmission line the best choice for receiving use. In transmitting applications, coaxial lines have little radiation loss and are not affected by objects, conductors, or other transmission lines in the vicinity. Compared to open wire lines, however, coaxial lines generally have significantly higher line losses and, for high power applications, are more expensive. The loss characteristics and the power handling capabilities depend largely on the dielectric material separating the conductors. Power handling capability is related to the distance between the inner and outer conductors and the ability of the dielectric to withstand the heat generated in the inner conductor. Coaxial lines are divided into rigid, semirigid, and flexible.

(1) *Rigid.* Rigid coaxial line is normally used: to connect high-power transmitter outputs to an antenna switching matrix, to an impedance matching device such as a balun or transformer, or to another type of 50 ohm coaxial line; or to enter or exit buildings. Rigid line has a tubular center conductor supported concentrically with respect to the outer conductor by discs or crossed pins made of dielectric material. The line sections are connected by flanges and use manufactured elbows to change direction. Diameters generally range from 2.2 to 15.6 cm (□ to 6 □ in.). Attenuation loss is generally less than for open wire lines.

(2) *Semirigid.* Semirigid coaxial line is generally used in moderate sized power systems to approximately 20 kW. The semirigid cable can be carefully bent on a radius of 10 to 15 times the diameter of the line. The inner conductor is tubular, except for the smallest lines, where it is solid. The inner conductor is supported within the outer conductor by a helix of polystyrene. The outer conductor is frequently of a spiral wrap semiflexible armored construction and is generally covered with a polyethylene or a vinyl protective covering. Attenuation losses are somewhat higher than those of open wire lines.

(3) *Flexible.* Flexible coaxial cable is the most popular transmission line for small and medium HF station applications. There are types of flexible coaxial lines available to meet more requirements. They range in size from 0.3 to 3.2 cm (□ to 1 □ in.) And they range in impedance from 50 to 150 ohms. Attenuation loss is quite high when compared to open wire, especially for the smaller cables.

(a) A flexible coaxial line consists of a solid or stranded wire inner conductor surrounded by a polyethylene dielectric. Copper braid is woven over the dielectric to form the outer conductor. The copper braid should be capable of providing at least 95 % shielding. Commercially available, inexpensive coaxial cable, providing only 60 % to 80 % shielding, should not be used. A waterproof vinyl or polyvinyl covering is placed over the woven braid. This outer insulating jacket is used solely as protection from dirt, moisture, and chemicals. These substances, if allowed to penetrate the insulating jacket, will contaminate the dielectric and will cause the cable to become lossy.

(b) As antenna transmission lines, flexible coaxial lines have their largest application in receiving systems. Receiving antennas with higher impedance, such as the log-periodics, ordinarily use coaxial cable with a matching transformer at the antenna end. Although coaxial cable makes a good impedance match to the center of a balanced half-wave antenna, without a balun the unbalanced nature of the coaxial line will cause a skew in the antenna radiation pattern.

(c) One advantage of flexible coaxial line is that it can be installed with almost no regard for its surroundings. It requires no insulation, can be run on or in the ground or in piping, can be bent around corners with a reasonable radius, and can be □snaked□ through places such as the space between walls where it would be impractical to use other types of line. Outside of the building, all permanent coaxial cable runs should be underground. The cable should be buried at least 50 cm (20 in.) in cold climates. The minimum burial depth is determined by the frost line or surface load. The cable should be cushioned with about 8 cm (3 in.) of sand below and above the cable, and planks should be laid above the top layer of sand prior to filling the trench. In this way the cable is protected from cuts if excavation is required. Concrete markers should be placed beside the trench at all turns to assist in location and protection of the cable. To minimize radio noise pickup on the receiving transmission lines, the matching balun should be installed on the termination pole of the antenna. The connecting coaxial cable is then run, preferably underground, to the receiver building. Cables for rf signals within the site building should be standardized at the same characteristic impedance, normally 50 ohms. Equipment with other characteristic impedances are matched to the 50 ohm rf line system by impedance matching transformers. Throughout the station, the rf cables should be physically grouped by service such as exciter cables, monitor cables, or patch panel cables.

b. *Open wire line.* An open wire line consists of two or more parallel wires of the same size, maintained at a uniform spacing by insulated spreaders or spacers at suitable intervals. These lines can be balanced or unbalanced.

(1) *Unbalanced open wire line.* The characteristic impedance of unbalanced, open wire lines ranges from 20 to 200 ohms depending on the construction. Unbalanced open wire lines are used primarily for impedance matching.

(2) *Balanced open wire line.* For transmission, balanced open wire lines are frequently preferred instead of coaxial transmission lines. At all but very low power levels, the open wire line costs less than coaxial line.

(a) Transmission line runs. For long transmission line runs, open wire balanced lines will have considerably smaller attenuation than will coaxial lines of comparable cost. The velocity of wave propagation is nearly that of free-space. The maximum voltage rating depends on the spacing of the wires and the type, size, and condition of the insulators. Construction details and installation practices for open wire rf transmission lines are contained in Air Force *Technical Orders*, TO 31-10-4 and TO 31-10-22.

(b) Feeder lines. Open wire line is especially suited for feeding most broadband balanced antennas such as the Vee antenna. Open wire feeders are relatively simple to construct. Materials required are two conductors of copper-clad steel or hard-drawn copper wire long enough to reach from the antenna feed connection to the balun, along with spacers and insulators. The spacers need to be of high quality insulating material such as polystyrene or phenolic material and long enough to keep the feeder conductors at a uniform 15 cm (6 in.) spacing. The spacers are installed at intervals sufficiently frequent to preserve the spacing and prevent the line from twisting and shorting out. The intervals between spacers vary from 1 to 2 m (3 to 6 ft.). The balun should be connected as close to the lower insulators as is safe and practical. Open wire lines should be treated with caution. At a transmitter power output of 1000 W, there are approximately 775 V on the wires.

5.2.6 Equipment performance requirements

- **Transmitting subsystem**

a. Typical HF transmitters. HF transmitters are available in many sizes and power ranges. Two power ranges, low power (below 1000 W) and medium power (1000 to 10,000 W), have been selected as representative of available equipment.

(1) *Typical characteristics of low-power HF transmitters:*

Frequency range	1.6 – 30 megahertz (MHz)
Output power	400 W
Operational modes	CW, USB, LSB, ISB, AM, FSK
Output impedance	50 ohms unbalanced
Frequency control	Synthesized frequency generator, integrally or remotely controlled, present frequency settings available
Tuning	Automatic with manual override
Cooling	Forced air, filtered

Cooling conditions	0° to 50° C (32° to 122°F) 90 % relative humidity
Input power	115/230 Volts alternating current (V ac) 50/60 Hz single phase 1200 W

(a) Installation. Transmitters in this power range are available for installation in standard equipment cabinets. A complete transmitter as described above can be installed in approximately 2 linear feet (1/3 meter) of cabinet space and would weigh about 160 kilograms (kg) 350 pounds (lb)). Two such transmitters can readily be installed in a standard 183 cm (72 in.) high equipment cabinet allowing adequate room between units for cooling.

(b) Operation. The typical low-power transmitter can be used in either fixed stations or transportable stations. Frequency is set by a synthesized exciter which may be removed from its normal position in the transmitter cabinet and located elsewhere within the station. It also has a capability for a number of preset channels.

(2) *Typical characteristics of medium-power HF transmitters.* Typical medium-power transmitters have the same general electrical characteristics as smaller transmitters. The notable differences are in size, weight, and input power requirements. Typical input power is 230 V ac, 50-60 Hz, 3-phase, 20,000 W. Typical size is 200 cm (78 in.) high, 140 cm (54 in.) wide, 100 cm (40 in.) deep, and the approximate weight is 1600 kg (3500 lb). The medium-power transmitter is normally installed in a single cabinet with power supplies on the bottom, final amplifier at the top, and control circuits in the center. Figure 5.4 is a typical diagram for a 10 kW transmitter.

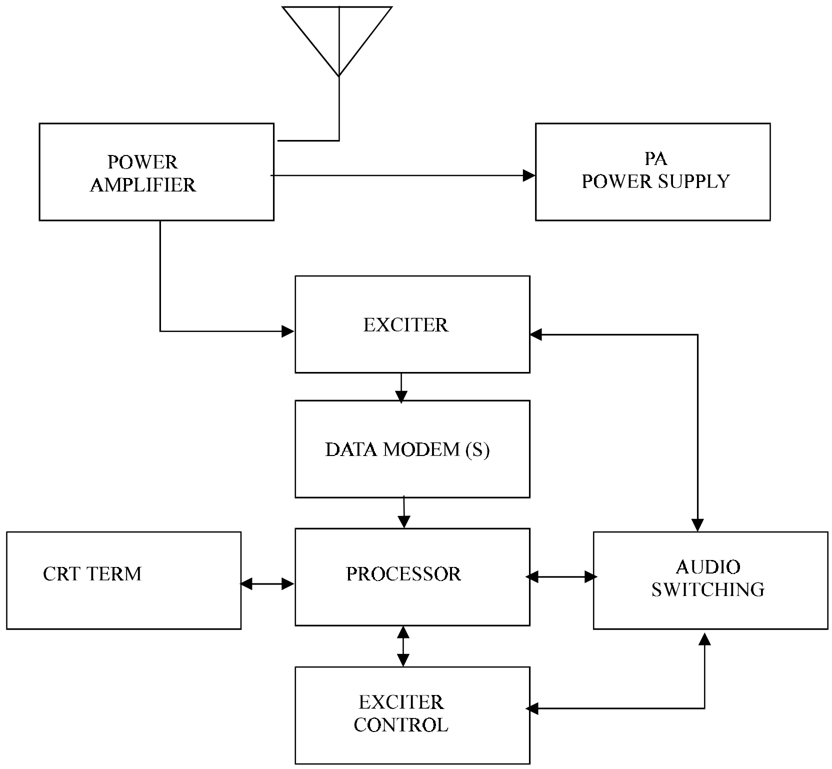


FIGURE 5.4

Example of 10 kW transmitter with automatic processor control.

- **Transmitting power**

Transmitting power is closely tied to the considerations to be made when considering propagation forecast. See Section 5.2.4 for details.

- **Receiving subsystem**

HF general coverage receivers are of two general categories. Fixed frequency receivers are designed with frequency settings dials or switches and are intended for single frequency operation for hours or days at a time. Variable or tunable receivers are designed for rapid frequency changing and are more suitable for signal search operations. They may have a frequency lock feature to prevent accidental frequency change. There are also some receivers available which cover both the HF and very high frequency (VHF) spectrum as part of their general coverage. Characteristics for each type of typical high quality generic receiver are listed below.

(1) *Single or multiple channel fixed frequency receiver.*

Frequency range	1.6 to 30 MHz
Frequency stability	1 part in 10^6
Operational modes	cw, USB, LSB, ISB, AM, FSK

Sensitivity	0.5 microvolts for 10 decibels (dB) signal-plus-noise-to-noise ratio (S+N)/N
Bandwidths	Selectable for 2.1, 3, and 6 kHz
Input impedance	50 ohms unbalanced
Temperature range	–30°C to + 50°C (–22°F to + 122°F) 95% relative humidity
Input power	115/230 V ac, 50/60 Hz, single-phase, 125 W 13 cm (5 in.) High, 48 cm (19 in.) wide, 48 cm (19 in.) deep, weight 45 kg (100 lb)

(2) *Continuous tuning, general coverage receiver.* The term *continuous tuning* is used here to indicate tuning is accomplished by a single dial as opposed a bank of switches or push buttons for setting a frequency.

Frequency range	2.0 to 30 MHz
Frequency stability	1 part in 10^6
Operational modes	cw, USB, LSB, ISB, AM, FSK
Sensitivity	0.6 microvolts for 10 dB (S+N)/N
Bandwidths	Selectable for 1.1, 2.1, 3, and 6 kHz
Input impedance	50 ohms unbalanced
Temperature range	0°C to 50°C (32°F to 122°F) 90% relative humidity
Input power	115/230 VAC, 50 to 400 Hz, single-phase, 125 W
Size	20 cm (8 in.) high, 38 cm (15 in.) wide, 36 cm (14 in.) deep, weight 12 kg (26 lb)

d. Typical HF transceivers. There are many types of transceivers available off-the-shelf. In general, most have power outputs in 100 to 200 W range and are ideally suited for use in small communications sites. A typical transceiver will be entirely solid state, including the final amplifier. Frequency can be changed rapidly, requiring no peaking or tuning. Stability is excellent requiring little or no adjustment between frequency changes. Transceivers are light weight and entirely self-contained, requiring only a microphone or key connected to the input and a suitable antenna connected to the output. The essential characteristics of a typical transceiver are as follows:

Frequency range	1.6 to 30 MHz
Frequency setting	Decade switches or continuous tuning by dial with frequency lock
Power output	150 W peak envelope power (PEP) or 100 W average
Operational modes	cw, USB, LSB, AM, FSK
Output impedance	50 ohms, unbalanced
Receiver sensitivity	0.5 microvolts for 10 dB (S+N)/N
Bandwidth	2.7 kHz for SSB, 375 Hz for CW
Size	18 cm (7 in.) high, 43 cm (17 in.) wide, 43 cm (17 in.) deep, weight 25 kg (55 lb)
Power input	115/230 V ac 50/60 Hz, single-phase, 400 W

e. Ancillary HF components. A transmitter or receiver usually requires certain peripheral items to constitute a complete operating system. Some of the common items used are described in the following paragraphs.

(1) *Exciters.* An exciter is a low-power transmitter which generates the modulated carrier frequency for the amplifier (transmitter) stages which follow. The exciter includes a signal input stage, a frequency synthesizer, a modulator, frequency translation stages, and a postselector. It may be more practicable from an operational standpoint to install exciters at some central point rather than have each individual transmitter with its own exciter nearby. A spare exciter could thus be available for any number of transmitters. Many types of frequency synthesized exciters are available having low-power outputs (up to 200 milliwatts (mW)) which are sufficient to drive higher power transmitters. Most transmitters in the 1000-watt and higher ranges are provided with an exciter module designed to be easily removed and operated from a remote location. Typical characteristics of a generic HF exciter are as follows:

Frequency range	2 to 30 MHz
Frequency selection	Rotary decade front panel switches
Modes of operation	cw, USB, LSB, ISB, AM, FSK
Power output	Variable up to 200 mW
Input/output	50 ohms unbalanced
Size	13 cm (5 in.) high, 48 cm (19 in.) wide, 51 cm (20 in.) deep, weight 16 kg (36 lb)
Temperature range	0°C to 50°C (32°F to 122°F) 95% relative humidity
Input power	115/230 V ac, 50/60 Hz, single-phase, 80 W

(2) *Low-pass filters.* Use of low-pass filters at the output of HF transmitters is often required. Since the frequency spectrum above 30 MHz is used by many low-power services susceptible to interference from harmonics of high-powered transmitters, it is necessary to use measures to suppress these spurious emissions as much as possible. Low-pass filters having attenuation of up to 60 dB at frequencies above 32 MHz are available for transmitter powers up to 40,000 W. The proper filters are included as an integral part of higher power transmitters.

(3) *Preselectors.* The purpose of a preselector is to minimize receiver overload from nearby transmitters and interference from adjacent rf channels. A preselector is required when the receiver must work in an rf environment that includes high levels of unwanted signals resulting in intermodulation and front-end overload problems. Preselectors are available which will provide protection to the receiver from signals as high as 200 volts at frequencies 10 % or more removed from the desired frequency. Typical specifications are as follows:

Frequency range	2 to 30 MHz
Bandpass	12 kHz

Noise figure	Not more than 12 dB
Input/output impedance	50 ohms unbalanced
Tuning	automatic from BCD (Binary Coded Decimal) frequency information
Tuning time	4 seconds maximum 13 cm (5 in.) high, 48 cm (19 in.) wide, 56 cm (22 in.) deep, weight 12 kg (27 lb)
Input power	115/230 V ac, 50/60 Hz, single-phase, 50 W

(4) *Independent sideband HF exciters.* By international agreement, ISB transmitters are permitted to have a 12 kHz bandwidth. This permits the transmitter to be modulated with four independent 3 kHz voice frequency sidebands. An exciter to drive and modulate the transmitter receives four independent voice frequency signals, converts them to higher single band signals, and combines them into a single band of modulating frequencies, 6 kHz above and 6 kHz below the transmitter frequency. The output of the exciter is at the transmitting frequency and is actually a very low-power transmitter having four independent sidebands. The purpose of the transmitter is to amplify these sidebands to a usable power level. Typical technical characteristics of an independent sideband HF exciter are as follows:

Frequency range	1.6 to 30 MHz
Frequency tuning steps	100 Hz
Audio inputs	600 ohms line input, 0 dBm
RF output	200 m W PEP with 1 mW input
Size	18 cm (7 in.) high, 48 cm (19 in.) wide, 56 cm (22 in.) deep, weight 14 kg (30 lb)
Power	115/230 V ac, 50/60 Hz, single-phase, 80 W

A simplified block diagram of an ISB exciter is shown in Figure 5.5. In this diagram, the four audio inputs are equalized in level in the audio amplifiers, which also provides for monitoring the audio. Each of the audio inputs is then converted in the modulators to an upper sideband, upper sideband, a lower sideband, and a lower sideband with a carrier frequency (suppressed) of 450 kHz. The four independent sidebands are then combined, translated, and filtered to a band centered at 9.45 MHz. The 9.45 MHz sideband signals are again translated to approximately 128 MHz to keep them well out of the range of 1.6 to 30 MHz to avoid interference and image frequency problems. At this point, they can be translated down by variable frequency oscillator (VFO) to the required range.

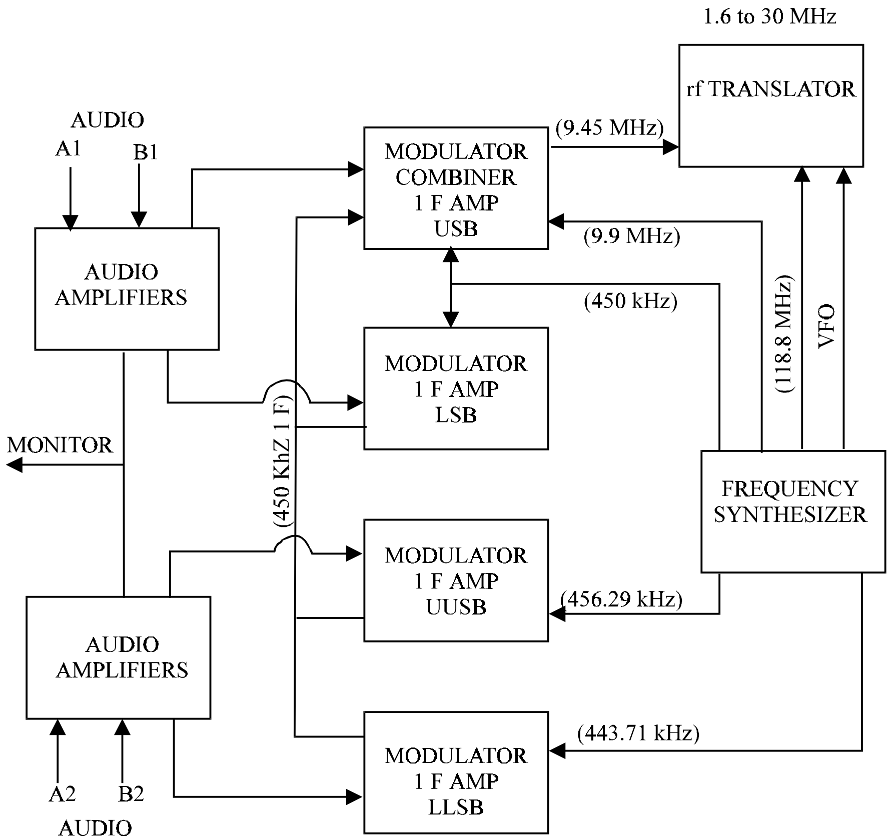


FIGURE 5.5
Block Diagram of an ISB exciter

- **Antenna subsystem**

Performance details for the antenna subsystem are outlined in Section 5.2.4, Propagation forecast, and in Section 5.2.7, Site/field surveys.

5.2.7 Site/field surveys

The primary technical objectives for a good HF radio site are to obtain the maximum signal-to-noise ratio at the receiver site and maximum effective power radiated in the desired direction from the transmitter site. Site topography affects the signal radiated from the transmitting site and signal arrival at the receiver site. The presence of natural and man-made noise detracts from the ability to obtain a good signal-to-noise ratio (SNR) at receiver sites. Desirable ground constants improve the performance of both transmit and receive antennas. These and other factors which enter into the selection of HF sites often involve compromises and trade-offs between economy, availability, and convenience. This chapter identifies items to look for in topography relative to terrain features and land-area requirements. Man-made radio frequency noise levels are defined for different areas. Site separation distances from noise sources are given. Earth constants in terms of resistivity and conductivity are discussed. General site requirements of availability, suitability, accessibility, and security are evaluated as to their influence on cost and practicality.

- **Topography**

The technically ideal HF radio site requires a broad expanse of flat, treeless land away from natural and man-made obstacles. Terrain flatness is necessary for uniform ground reflection of the antenna radiation. Obstacles may mask portions of the signal-radiation path at transmit and receive sites.

a. Site terrain features. The nature of the terrain in front of an antenna has a significant influence on the vertical radiation pattern. A good antenna site will have a smooth reflection zone and will be free of obstacles which may block the radiation path.

(1) *Reflection zone.* The reflection zone is the area directly in front of the antenna that is required for the reflection of the ground-reflected component of the skywave signal. The surface of the reflection zone should not have any abrupt changes in elevation greater than 10% of the antenna height nor a slope greater than 10% in any direction. Surface irregularities in the area should be limited to 0.1 wavelength in height at the highest operating frequency. The reflection zone at fixed sites and wherever else practicable should be cleared of all trees and brush. A low ground cover of grass, clover, or similar growth should be maintained for erosion control.

(2) *Obstacles.* In the direction of propagation, any substantial obstruction (such as a terrain mass, man-made structures, and trees) should subtend a vertical angle less than one-half of the angle between the horizontal and the lower 3-dB point of the required takeoff angle. See Figure 5.2. At potential HF sites where obstructions are likely to be encountered, a manually plotted site azimuth-elevation profile should be made. Elevation profile records are also useful for future planning in the event of expansion. Such a profile may be drawn by using a transit and a compass with azimuth readings corrected for the local magnetic variation. Normally, plotting the elevation in 10° increments of azimuth will be satisfactory. A method of plotting an azimuth-elevation profile is contained in appendix B of FM 11-487-4/TO 31-10-24.

b. Land area requirements. The area required for an HF site depends upon the size and number of antennas, the spacing between antennas, the clearance required for ground reflection, and the clearance required to avoid mutual coupling. In addition to known initial plans, space should usually be set aside for unspecified future antenna field expansion. Sites may vary from a minimum of a few acres for a small site to up to 60 acres for a medium-sized site. The land area requirements are determined by the system planner, based mainly on antenna field layout as discussed in 5.2.4, Propagation Forecast.

- **Environmental rf noise**

For reliable reception of weak signals from distant stations, the receiving antennas must be located in an electromagnetically quiet area relatively free from man-made noise. At HF, there are three major sources of rf noise: galactic, atmospheric, and man-made. The latter is of chief concern since it is the only source over which some control can be exercised. At many locations the noise from power lines dominates in the lower part of the HF band. Ignition noise from motor vehicles tends to predominate over power-line noise in the upper part of the HF band. Any strong, nearby source can be dominant in controlling the noise environment. The importance of locating an HF site in a quiet area is discussed in Section 5.2.4. A comparison between the values of man-made noise levels for "*quiet*" "*rural*", "*rural*", "*residential*", and "*business*" areas shows an extreme difference of approximately 25 dB. Further information on man-made noise is contained in U.S. Department of Commerce OT Report 74-38.

a. Site separation. Radio transmitters located within several miles of a receiving station may create serious interference due to harmonics or co-channel operation. In addition, intermodulation products may be generated in receivers due to intense radio energy fields from nearby transmitters even when operated on widely separated frequencies. Radio receiver and transmitter sites must be isolated from each other, from other radio facilities, and from heavily traveled highways, cities, and industrial areas. Exceptions are sometimes required for small sites where antennas may be as close as 305 m (1000 ft) from each other. Transmitters with less than about 1 kW of transmitting power can be collocated with receivers if special attention is given to frequency selection. The use of rf filters may be necessary at collocated sites.

b. Ambient noise level surveys. Field-strength surveys should be made at receiver sites to evaluate the level and population of unwanted signals, to establish the ambient noise level, and, if possible, to locate sources of rf interference. A simple ambient noise survey can be conducted using an HF receiver with a signal strength meter (S-meter) and a portable antenna such as a whip or dipole. The receiver should be tuned to unoccupied frequencies near or on the intended operating frequencies. The test should be set up in the same configuration at each site if comparison tests are to be made. Noise measurements can be made by recording the S-meter readings when the receiver is tuned to unused frequencies. The receiver should be set to the AM position if it has one. A crude but useful test can be conducted with a hand-held battery powered AM broadcast receiver. Noise crashes are usually from thunderstorms within reception range. Hums, splattering, periodic noises and some noise crashes may be heard which can identify troublesome man-made noise sources. An initial survey with mobile equipment is recommended to spot check main highways and country roads in the vicinity of the site. The survey should identify noise sources and give an indication of the interference levels. A survey should be conducted from near the center of each receiver site being considered for comparison purposes. This survey should extend over sufficient time (usually several days) to gather statistically significant data for the noise characteristics of the site. Noise field strength measurements must be recorded to determine the ambient noise level of the site throughout the frequency spectrum of interest at various times of the day.

- **Earth constants**

Resistivity and conductivity of the earth and the relative dielectric constant at the HF site should be considered during site selection. The resistivity of the earth affects the quality of the earth electrode grounding system. The method of measuring the resistance-to-earth of grounding electrode systems is described in chapter 9 of FM 11-487-4/TO 31-10-24 and other documents. Soil resistivity measurement techniques are described in MIL-HDBK-419. Good conductivity of the earth increases the range of ground-wave propagation and lowers the take-off angle of skywave signals, thereby increasing their range. Ground conductivity is difficult to measure accurately. However, it may be estimated by the nature of the terrain.

- **General site requirements**

In addition to the technical factors, other important features of a general nature should be considered when selecting HF sites. They are as follows:

Availability
Suitability
Accessibility
Security

a. Availability. Land which meets the flatness criteria of an HF site is generally prime construction land or agricultural land. When this land is acquired in the acreage required even in small sites, it can be very expensive. In fact, land acquisition may be the single greatest expense in the project. Therefore, the site selector should always consider the use of existing facilities. The least expensive siting of an HF installation is to use and expand an existing HF site. The next least expensive choice is the use of unoccupied land already available to the Government. Land use within a military installation is normally controlled by the facility engineer. Non-military Federally owned land is controlled by various U.S. Government agencies, the primary one being the Bureau of Land Management.

b. Suitability. The general suitability of a potential site is dependent upon the magnitude of construction required for site development, implementation, and maintenance of facilities. The existence and capacity of nearby utilities such as electrical power, water, gas, and sewage disposal are important factors in site selection. Information relating to geological conditions such as soil and drainage data, wind and weather data (including icing conditions), and seismic activity should be gathered and considered. Soil and drainage data should be available from the supporting facility engineer. Wind and weather data are available from area weather stations, while records on seismic activity are usually available from the U.S. Geological Survey (USGS) or from a nearby university geophysics department.

c. Accessibility. Access to HF sites should be supported by the existence of adjacent roads and highways leading to the site. Conditions such as slopes, constrictions, curves, overhead and side clearances, surfacing, turnouts, and weight limitations on bridges and culverts should allow transportation of equipment during installation as well as during support operation and maintenance after installation. The facility engineer should be consulted about existing road conditions or for new road construction.

d. Security. HF radio site selection should consider provision for fences, area lighting, guard and alarm systems, proximity to other facilities, enemy threat, and defensibility of the local terrain. Transportable HF radio sites should be located to take tactical advantage of terrain obstacles, observation, and fields of fire, and to avoid possible enemy avenues of approach. In areas under enemy threat, it may be necessary to combine the transmitter and receiver sites to reduce vulnerability and to concentrate defensive forces. Physical security techniques are addressed in chapter 13 of FM 11-487-4/TO 31-10-24.

- **Site survey procedures**

Site surveys are conducted for the purpose of determining the technical and general suitability of land for an HF transmitting or receiving site. Each survey will have unique requirements for the number and size of transmitters, number of receivers, and the land and topography requirements for antennas. The process of selection of a site for a radio transmitting or receiving facility involves three distinct steps.

a. The first step entails map studies, ownership studies, logistics studies, and long range planning to select several tentative candidate areas.

b. The second step consists of teams who conduct preliminary site surveys to gather general site information of all the likely candidate areas. From the general site information, the list of candidate sites is then reduced to a potential few.

c. The third step involves survey teams who visit one or more of the final sites selected. The teams will gather detailed information which will be analyzed to determine the adequacy of the site or sites. From this information, a decision is made as to the best site to use for the facility. Appendix B of MIL-HDBK-420 contains procedures for conducting HF site surveys including a worksheet, which presents a general format that may be followed in preparing a site survey report. MIL-HDBK-420 is a general reference to communications site surveys.

- **Construction plans**

There is no standard configuration for the layout of HF radio sites. This is due to the wide variations in the makeup of HF radio stations. Some factors and considerations in HF station layout and development are contained in this chapter. When developing fixed small- and medium-sized HF systems, the selection of buildings, land, and related physical plant is usually limited to the modification of existing facilities. The development of HF radio communications systems within existing buildings and antenna layout on the existing land becomes a task of adapting the new system to available facilities. Antenna field layout specifications are governed by the area available to provide reflection zones and the clearances required to avoid mutual coupling between antennas. Other factors involve separation for purposes of diversity reception and consideration of interconnections between antennas and equipment. Typical site layouts which may serve as a point of departure to the site layout designer are depicted in this chapter. The development of HF transportable sites is also discussed in this chapter. The early establishment of the sequence of installation is the key to the orderly development of transportable HF communications. The transportable site development material in this chapter is intended to supplement the instructions in equipment technical manuals. This material is related to management and administration rather than specific technical details found in equipment manuals.

- **HF antenna layout**

One of the most important factors in the successful performance of HF radio communications is the correct positioning of antennas to provide maximum performance. An HF antenna layout requires a practical balance between choosing good sites, taking advantage of natural terrain features, separating noise sources, and taking into consideration the requirements for logistic support and accessibility. These factors were introduced in the Section 5.2.7 discussion of HF site surveys. HF antenna layout within a selected site involves three determinations: the requirements relating to the reflection zone area, the mutual separation clearances, and the physical layout of related facilities.

a. Reflection zone areas. The reflection zone is the area required in front of an antenna for the formation of the ground reflection lobe. The main lobe of an HF transmitting or receiving antenna is formed by the interaction of the direct radiation and the reflection from the ground plane. The ideal reflection zone has the following characteristics: a) it is perfectly smooth, unobstructed ground or water; b) it is of sufficient size as determined by the operating frequency and take-off angle, and c) it is an elliptically shaped area with the major axis in the direction of the radiation pattern of the antenna.

b. Mutual coupling. Mutual coupling is the effect of one antenna on another antenna when both antennas are located in the same general area. Mutual coupling occurs:

- when the radiation pattern of one antenna passes through another antenna;
- when antennas interact by being too close; or
- when an antenna couples to a metal object or structure.

Mutual coupling may alter the radiation pattern of the antenna, may cause high reflection losses, may change the resonant frequency, or may introduce interference in other systems. Mutual coupling may be calculated as a function of the distance of separation, frequency of operation, and antenna gain. Table 4.2 of FM 11-487-4 gives simplified minimum clearances required by typical antennas at normal operating frequencies.

c. *Other antenna siting considerations.* In addition to separation distances to avoid mutual coupling, space diversity antennas must be separated to perform properly. Receive antennas operating in space diversity mode should be separated from each other by a minimum of 300 m (1000 ft) and, where space permits, by five wavelengths at their lowest operating frequency. Space diversity antennas should be located for both lateral and forward separation. Other considerations are:

1. Requirements for a spare antenna,
2. Room for future expansion,
3. Short and direct transmission-line runs,
4. Orderly arrangement of the transmission line,
5. Building entrance,
6. Equipment location with the building,
7. Separation between transmission lines,
8. Clearance of service roads and obstructions from in front of antennas.

- **Typical fixed site layout**

The physical size and layout of an HF facility are dictated by the communications traffic that the facility is expected to handle. Simple HF antennas often require space of less than one acre, however, a single large fixed HF antenna may require up to 15 acres. A small transmitting facility could consist of a single transmitter using a rotatable long-periodic (RLP) or Yagi antenna for transmission on different azimuths. A similar receiver site separated some distance for isolation could also contain remote control facilities for the transmitter. A single-circuit facility may have a transmitter and receiver collocated and may use the same antenna in simplex mode. A medium sized facility could consist of several fixed antenna systems serving an equal number of transmitters and receivers at separate sites up to 16 km (10 mi) apart. A large HF facility may consist of rows of equipment and hundreds of acres of antenna farms. Discussion of large fixed sites is beyond the scope of this manual.

a. *A typical small site.* The small HF facility layout shown in Figure 5.6 is typical of MARS stations and of stations operating in a small single HF command net. Such stations usually employ a single site layout, that is transmitters and receivers that are collocated. The emission mode is typically limited to cw, SSB, and RTTY. This configuration may consist of one or two fixed-azimuth antennas and an RLP antenna. The Vee antennas shown may be used for daily scheduled point-to-point medium range communications. The RLP antenna is useful for communications to a number of points at different times. In the configuration shown in Figure 5.6, one Vee antenna may be used for receiving and the other for transmitting. The RLP antenna can serve as a general purpose antenna for a simplex link. The dipole antennas, oriented 90° apart, can be added either for short distance links or as a receive antenna to check propagation. The antenna layout should facilitate the shortest and most direct transmission-line runs. The central location of the building avoids crossing of transmission lines. The single-access road diverts vehicular traffic away from high-powered radiation patterns.

b. *A typical medium sized site.* Separation of receiving and transmitting sites is one of the chief differences between smaller and larger facilities. One of two sets of transmitters and receivers can usually interoperate with relatively little interference with careful frequency selection. However, several high-powered transmitters will generate such interference problems in collocated receivers as to make the situation intolerable. A typical medium sized HF facility is shown in Figure 5.7. In this typical configuration, four sets of rhombic antennas are shown at distances of approximately 400 to 900 m (1300 to 3000 ft) from the operations building (receiving or transmitting). Transmitting antennas of large size, and at high power, are usually fed with open wire or rigid coaxial transmission lines. Such lines must be installed in the shortest, most direct path. At transmitting sites, antennas having the same orientation may be used alternately by separate transmitters for frequency changing with minimum loss of transmitting time. At receiver sites, antennas having the same orientation would be used as spares or as one of a diversity pair. The two RLP antennas and three monopole antennas shown may be used for coverage of azimuths not covered by rhombic antennas or may be used as spare antennas. Auxiliary power installations are sometimes required at larger HF sites. Generator power installations of 100 kW output power or less may be integrated into the operations building complex, but ideally are installed in a separate building near the operations building. Power building should be of well-bonded metal construction with fuel storage facilities. Fuel storage may be in above-ground tanks near the power building, but ideally should be buried and located with a diked area at least 10 m (30 ft) from the power building.

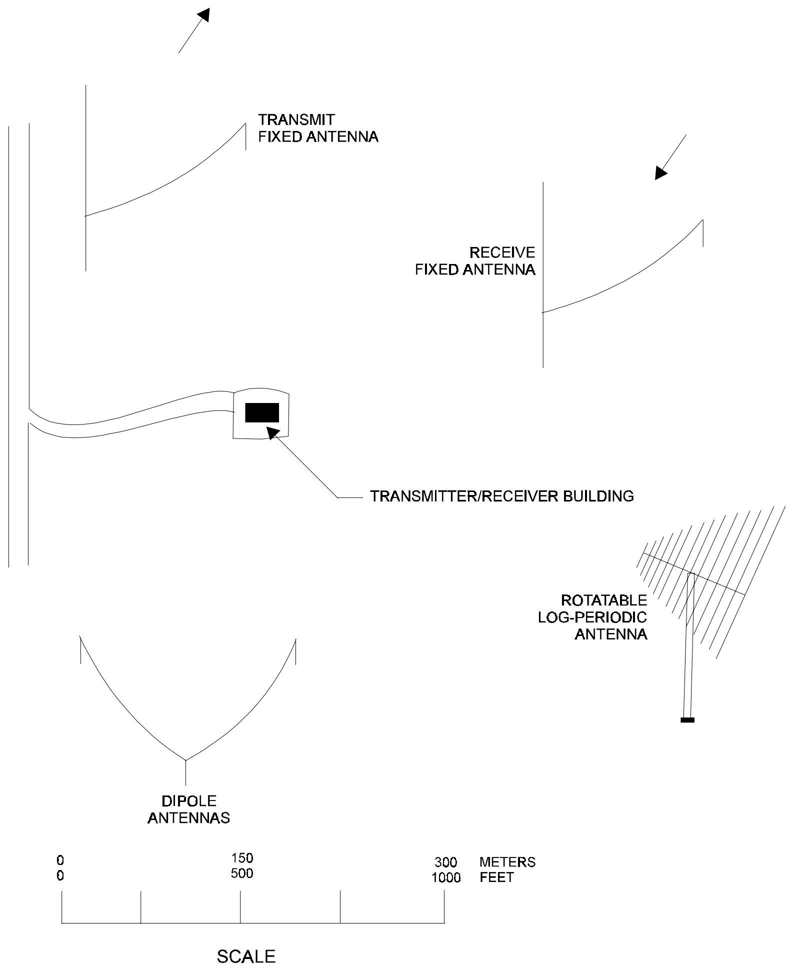


FIGURE 5.6

Typical small sized HF facility

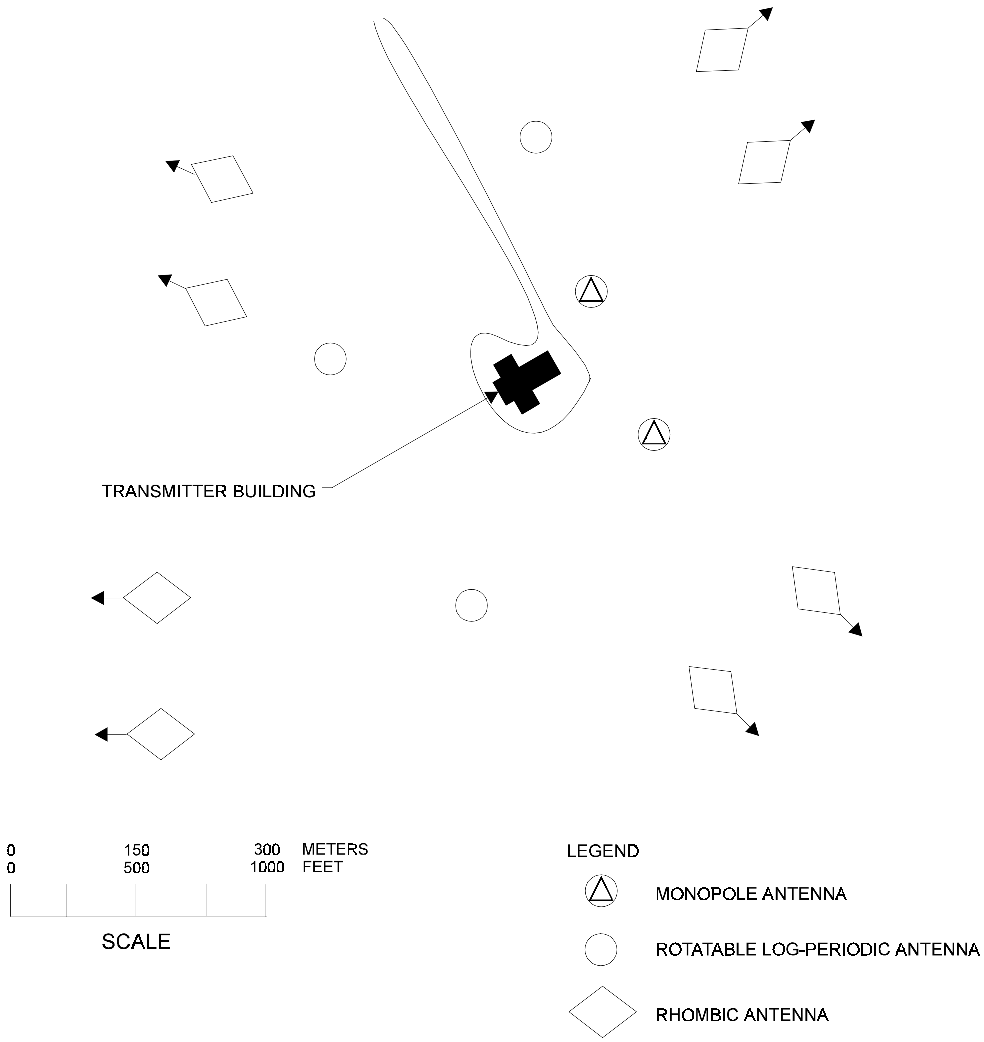


FIGURE 5.7
Typical medium sized HF facility

- **System test and evaluation plans**

An important part of any installation is to perform a system test and to evaluate the installation in a performing environment. As the system analysis and design phase progresses, thought should be given to how the system will be tested and evaluate after installation. One of the important steps that the system implementer and system engineer should generate is a System Test and Evaluation Plan that will be carried out as soon as installation and operation has begun. In cases where a network is involved, the network manager should be involved and the Network Design Plan should be considered an integral part of final system test. Areas that should be included in a System Test Plan might be:

- System Performance
- Network Performance
- Data and Message Throughput
- Power Considerations
- Physical and Network Security

5.3 System test

As the third phase of installation of the HF radio system, the system test and evaluation plan must be implemented. Possible areas that should be examined might include:

- System performance:
  - operating all equipment, which includes adjusting transmitter power, reading meters, rotating antennas, *etc.*,
  - equipment functioning properly:
  - transmitters, and receivers operating within specifications) ,
  - antenna performance:
  - are we reaching all the stations we wish
  - are radiation patterns as expected
  - environmental noise as expected.
- Network performance:
  - proper network connectivities,
  - proper network capabilities,
  - reasonable congestion,
  - reasonable number of system faults,
  - proper software installation,
  - network routing tables being filled properly,
  - linking protection scramblers functioning properly.

- Data and Message Throughput:
  - linking properly with all stations,
  - priority message handling adequate,
  - data message throughput adequate.

- Power considerations:

-adequate power for all operations, including emergency conditions
-clean power with only minor noise and fluctuations

- Review site security plan:
  - physical security adequate on all parameters
  - no hazardous conditions left from construction or implementation
  - network security is functioning

5.4 Conclusion

HF radio design process is not difficult if the proper up-front planning is done and the system engineer or system implementer understands just what is to be accomplished. To summarize the major steps:

1.The definition and analysis of the requirements should be detailed in a preliminary system design and feasibility study. This plan outlines requirements for frequencies, personnel, support, local issues, communication type, reliability, real estate, environmental impact, milestone dates, *etc*. Also included should be a detailed cost estimate of all known aspects of the design.

Individual steps to be accomplished in the system design are listed in Table 5.7.

TABLE 5.7
Step-by-step system design procedures

Step #	Task to be Accomplished
1.	Prepare system block diagram
2.	Tentatively select sites for HF equipment
3.	Determine final site locations from field survey data.
4.	Determine total required system gain.
5.	Develop a detailed block diagram for each facility.
6.	Research possible equipment sources – military inventory and commercial
7.	Write specifications for equipment not in the inventory.
8.	Develop equipment subsystem application drawings for each facility.
9.	Determine equipment installation requirements for installation.
10.	Complete installation package. (Specifications and drawings).
11.	Prepare acceptance test procedures for each equipment, subsystem, and the total system.

2. A system analysis and design is then completed, to identify the details of the network topology, operational parameters, propagation forecast, equipment selection, performance issues, site

surveys, and construction plans. Also included in the system design is the writing of a plan for system test and evaluation.

3. The third phase is the system test and evaluation phase where details of system are checked for proper performance.

The system engineer, system implementer, and network manager must fully cooperate and to assure that all details of the system design and network design are properly coordinated and completed.

With careful management, the HF radio system can be a valuable asset to the communication needs of the typical user. HF propagation has many valuable attributes and a few weaknesses. Through the use of proper planning, many of these weaknesses can be overcome.

.5.5 Summary of applicable standards

Many military and civilian standards exist that can be used for details when doing a system design or feasiblity study.

5.5.1 Federal Telecommunications Standards

FED STD 1037 C - Telecommunications: *Glossary of Telecommunication Terms*
FED STD 1045 A - Telecommunications: *HF Radio Automatic Link Establishment*
FED STD 1046/1 - Telecommunications: *HF Radio Automatic Networking, Section 1: Basic Networking-ALE Controller*
FED STD 1049/1 - *Telecommunications: HF Radio Automatic Operation in Stressed Environments, Section 1: Linking Protection*
FED STD 1052 - Telecommunications: *HF Radio Modems*

5.5.2 Federal Information Processing Standards (FIPS)

Federal Information Processing Standards (FIPS Pubs) are computer standards for use by the Federal Government. Some have adopted TIA/EIA industry standards and some are re-numbered Federal Standards. If interface of computer equipment with radio equipment is desired, then the appropriate FIPS Pub must be utilized for Government projects.

5.5.3 Military Standards

MIL STD 187-721 C - *Interface and Performance Standard for Automated Control Applique for HF Radio*
MIL STD 188-110 A - *Interoperability and Performance Standards for HF Data Modems*
MIL STD 188-114 - *Electrical Characteristics of Digital Interface Circuits*
MIL STD 188-124A - *Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communication Systems*
MIL STD 188-141 B - *Interoperability and Performance Standards for Medium and High Frequency Radio Equipment*
MIL STD 188-148 - (S) *Interoperability Standard for Anti-Jam (AJ) Communications in the High Frequency Band (2-30 MHZ)* (U)
MIL STD 461 - *Electromagnetic Interference Characteristics Requirements for Equipment*
MIL STD 462 - *Measurement of Electromagnetic Interference Characteristics*
MIL STD 463 - *Definition and System of Units, Electromagnetic*
MIL STD 882 - *System Safety Program Requirements*
MIL STD 1472 - *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities*

5.5.4 Military Handbooks

MIL HDBK 216 - *RF Transmission Lines and Fittings*
MIL HDBK 411 *Long-Haul Communications (DCS) Power and Environmental Control for Physical Plant*
MIL HDBK 413 - *Design Handbook for High Frequency Radio Communications*
MIL HNBK 419 - *Grounding, Bonding, and Shielding for Electronic Equipments and Facilities*
MIL HDBK 420 - *Site Survey Handbook, Communications Facilities*

5.5.5 DISA (DCA) engineering standards

DCAC 300-95-1 – *Planner's Guide to Facilities Layout and Design for the Defense Communications System Physical Plant*
DCAC 300-175-9 - *DCS Operating-Maintenance Electrical Performance Standards*
DCAC 330-175-1 *DCS Engineering-Installation Standards Manual*
DCAC 330-175-1 *DCS Engineering-Installation Standards Manual, Addendum No. 1, MF/HF Communications Antennas*
DCAC 370-160-2 *DCS Circular- Site Surveys, Site Selection and Construction Design Criteria*
DCAC 370-160-3 *DCS Circular - Site Survey Data Book for Communication Facilities*
DCAC 370-185-1 - *DCS Applications Engineering Manual, Volume II*

5.5.6 Military Department Standards (Army, Navy, Air Force Technical manuals/Technical Orders, Post/Camp/Station Regulations or Directives)

AFCCP 100-6, *Communications-Electronics Activities-High Frequency Radio Communications in a Tactical Environment*
TO 31-10-4, *Air Force Standard Installation Practices*
TO 31-10-19, *Air Force Standard Installation Practices Antenna Systems—Anchors and Supports*
TO 31-10-22, *Air Force Standard Installation Practices-Antenna Systems—Open wire RF Transmission Lines*
TO 31-10-23, *Air Force Standard Installation Practices-Antenna Systems—HF Rhombic Antennas*
TO 31-10-28, *Air Force Standard Installation Practices--Erection of Steel Towers*
FM 11-65, *Army Manual—High Frequency Radio Communications*
FM 11-486-7/TO 31Z-10-22, *Army/Air Force Manual—Telecommunications Engineering-Electrical Power Systems for Telecommunications Facilities*
FM 11-486-8/TO 31Z-10-34, *Army/Air Force Manual—Telecommunications Engineering-Alternative Energy Sources*
FM 11-486-24/TO 31Z-10-25, *Army/Air Force Manual--Digital Data Transmission Error Protection*
FM 11-487-4/TO 31-10-24, Army/Air Force Manual -- Installation Practices: Communications Systems Grounding, Bonding, and shielding
NAVELEX 0101, 0102--*Naval Shore Electronics Criteria Naval Communications Station Design*
NAVELEX 0101, 0103--*Naval Shore Electronics Criteria HF Radio Propagation in Facility Site Selection*
NAVELEX 0101, 0104--*Naval Shore Electronics Criteria HF Radio Antenna Systems*

5.5.7 National (ANSI, IEEE, TIA/EIA, NEC) standards

IEEE C95.1-1991 - *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*
ANSI/IEEE STD 473-1985 - *IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz)*

EIA Standard RS-232C-*Interface between Data Terminal Equipment and Data Communications Equipment Employing Serial Binary Data Exchange*
EIA Standard RS-258-*Semi-flexible Air Dielectric Coaxial Cables and Connectors, 50 Ohms*

5.5.8 International Standards (NATO, ITU-R Recommendations)

STANAG 4203	Technical Standards for Single Channel HF Radio Equipment
STANAG 4285	Characteristics of 1200/2400/3600 Bits per Second Modulators/Demodulators for HF Radio Links
STANAG 4415	Very Robust Version of 188-110A Single Tone
STANAG 4444	Slow Hopping HF Electronic Protection Measure
STANAG 4481	Naval HF Ship-to-Shore Broadcast System
STANAG 4529	Narrowband Version of 4285 Single Tone Appendix A
STANAG 4538	Automatic Radio Control System (ARCS)
STANAG 4539	Nonhopping Equivalent for Annex C of 4444
STANAG 5035	Introduction of an Improved System for Maritime Air Communications on HF, LF, and UHF
STANAG 5066	Profile for Maritime High Frequency Radio Data Communications
STANAG 5066 ANXG	Waveforms for Data Rates Above 2400 bps
QSTAG 733	Technical Standards for Single Channel High Frequency Radio Equipment

ITU-R RECOMMENDATION 455-1	Improved Transmission for HF Radiotelephone Circuits
ITU-R RECOMMENDATION 520	Use of High Frequency Ionospheric Channel Simulators